Phase Calibration for Ideal Wideband Chirp in Satellite-based Synthetic Aperture Radar

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Abstract

Satellite-based synthetic aperture radar (SAR) can acquire high-resolution images at day and night regardless of the weather. Since SAR resolution is determined by bandwidth, corresponding generation of wideband chirp is essentially required for high-resolution SAR image under consideration of relatively small and light weight SAR system. Therefore, an ideal chirp generation, which is challenging task in actual hardware, is proposed by modifying chirp equation for phase calibration and verified based on Sentinel-1 satellite parameters. The proposed method is applied to our SAR system and evaluation results using SAR observation simulation show that the impulse response is enhanced.

Ⅰ. Introduction

Research on satellite onboard synthetic aperture radar (SAR) observations for enemy surveillance and natural disaster monitoring is being actively conducted. SAR has the advantages of all-weather observation. In SAR parameter, the bandwidth is related to range resolution, which is the beam emitting direction, so that the chirp which is one of linear frequency modulation is used to increase the bandwidth in SAR system [1]. By using chirp shaped pulse, SAR has a better range resolution. However, with better resolution, the system is more sensitive to noise and requires elaborate hardware. In addition, a high system clock is required for wide bandwidth output and the system noise inevitably occurs in the high clock environment. Phase distortion correction is suggested in [2]. Authors of [2], studied hardware calibration in RF frequency, however, they did not consider the quality of calibrated chirp signal.

In this paper, we conduct phase calibration for generation of ideal wideband chirp under the system noise situation. In order to implement ideal phase, we formulate chirp phase equation and configure phase accumulation blocks using Simulink.

Ⅱ. Mathematical Analysis

2.1 Chirp pulse signal

In normal radar system, pulse is used to detect the object which is very fast, such as the missile and the military aircraft. The detection accuracy (δ) can be expressed as $\delta = \tau \times c/2$, where τ and c are pulse width and speed of the light, respectively. Although short pulse can enhance the accuracy, there is limitation in terms of system implementation. Thus, the chirp shaped pulse is adopted in SAR system. The chirp is implemented as linear frequency modulated signal and has large time bandwidth product characteristics. Therefore, larger frequency variation, i.e. wide bandwidth, enhances the resolution.

2.2 Phase calibration in actual SAR system

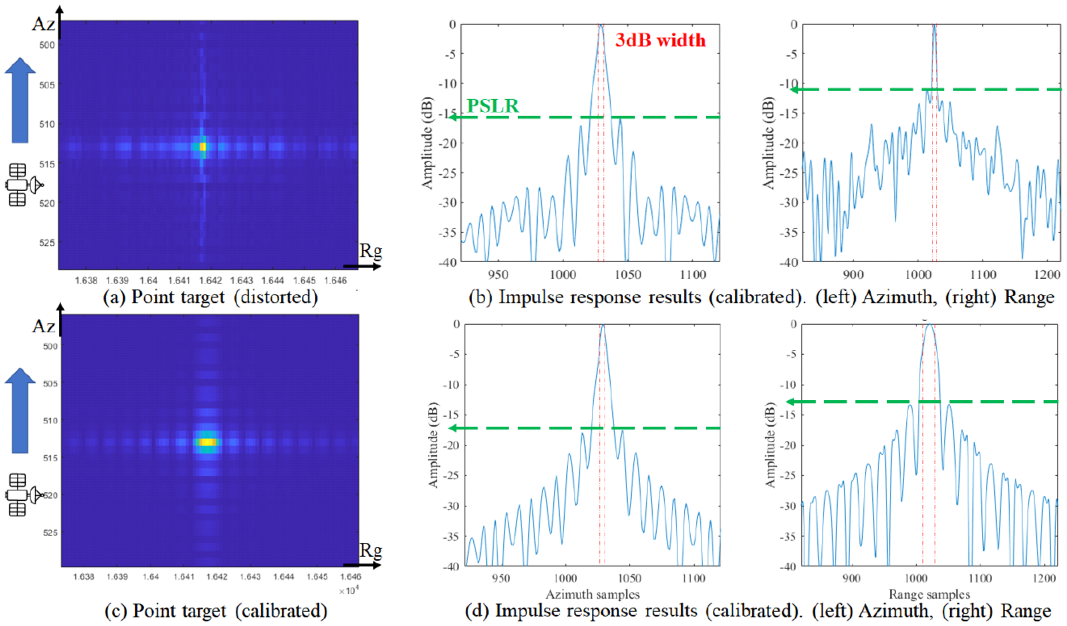
For measurement the chirp characteristics, our developed SAR system is used. Size and weight of our SAR system are smaller than 2U and less than 4 kg, respectively. Our hardware generates wideband (500 MHz) chirp pulse using FPGA (Kintex-7) and DAC (E2V). Then it up-converts baseband to RF frequency for measuring the frequency spectrum and the phase. Although simulation results show ideal chirp pulse, hardware output is measured with the phase distortion. The phase distortion from RF imbalance and non-linearity causes signal distortion and image resolution degradation. To calibrate the measured phase distortion, frequency and phase term can be formulated as follows:

$$\phi(t) = \frac{1}{2}\frac{f_1 - f_0}{\tau}t^2 + f_0 t + \phi_0 + \phi_{cal}(t), \qquad (1)$$

where f_1 and f_0 are last and initial frequency, respectively. ϕ_0 is initial phase and $\phi_{cal}(t)$ is added for phase calibration with respect to time. According to predistortion method in wideband chirp generation, our SAR system can be calibrated. Using (1) and several Xilinx blocks in Simulink, chirp pulse is easily generated. However, there requires additional functions which consider FPGA specification, especially system clock, to calibrate phase value. We accurately measure the phase error and convert the error to the Simulink values. After that, predistortion blocks using second order regression are added into phase accumulation stage. Moreover, we divide the error into sub-error interval, so that each sections can be optimized.

Ⅲ. SAR Observation Simulation

Suppose that satellite-based SAR observes point target and synthesizes SAR images. The point target is located at middle range of beam area. Since SAR has 3.41 degree of elevation angle, the range swath width is 40 km (at one IW) with 865 km of middle slant range.



(a) Point target (distorted) (b) Impulse response results (calibrated). (left) Azimuth, (right) Range

(c) Point target (calibrated) (d) Impulse response results (calibrated). (left) Azimuth, (right) Range

Figure 1. Point target and impulse response analysis for distorted (a), (b) and calibrated (c), (d) signal.

SAR emits the beam to range direction during flight to azimuth direction. The beam containing chirp pulse is transmitted every pulse repetition interval until synthetic aperture time. In our simulation, SAR system generates distorted signal and calibrated signal for comparison each impulse response function qualities. We acquire observation raw data by processing transmitted signal with receive signal. Then, the raw data is synthesized into the point target using range-Doppler algorithm. The results of point target synthesizing and the impulse response analysis are shown in Figure 1. Figure 1(a) and (c) are point targets which are observed using distorted and calibrated signal, respectively. In our simulation, satellite-based SAR flight from bottom to top (y-axis), and beam is emitted to right side (x-axis). In Figure 1(a), if there is distortion in the signal, even though Sentinel-1 parameters are used, the result shows also distortion. In case of using calibrated signal, the restored point target shows nearly uniformed as shown in Figure 1(c). Figure 1(b) and (d) are impulse response results of point target. Each left side means analysis result in azimuth direction, i.e. y-axis of Figure 1(a) and (c). Each right side shows range IRF result reflecting the signal characteristics.

For qualitatively analyzing IRF results, we use two evaluation metrics, e.g. peak to side-lobe ratio (PSLR) and integrated side-lobe ratio (ISLR) [3]. IRF analysis results with signal quality are summarized in Table 1. Using calibrated signal, side-lobes are suppressed to -1.71 dB in azimuth PSLR and -2.32 dB in range PSLR, respectively. Since SAR beam emission affects to range characteristics, IRF shows worse qualiy in range direction. The power ratio, i.e. ISLR, is little enhanced to -0.11 dB in azimuth and -0.07 dB

Table 1. IRF analysis results according to signal quality.

Qualiy	Metic	Azimuth	Range
Distorted signal	PSLR (dB)	-15.88	-10.91
	ISLR (dB)	-16.43	-19.18
Calibrated signal	PSLR (dB)	-17.59	-13.23
	ISLR (dB)	-16.54	-19.25

in range. Simulation results using distorted signal show that quality of the synthesized point target has degraded, however, ISLR is decreased little, because the main-lobe of range direction (Figure 1(b) right) is sharp.

Ⅳ. Results

In this paper, a phase calibration in satellite-based SAR is proposed for ideal wideband chirp generation. Our own hardware is used for measurement of distorted signal. To calibrate the phase distortion, we re-configure chirp generation blocks and add phase calibration blocks. In SAR observation simulation, Sentinel-1 raw data parameter is used for data reliability. SAR observes the point target and synthesizes the observed data using focusing method. Then, the restored point target is analysed using IRF method. The IRF results demonstrate that the calibrated signal leads to performance enhancement in both direction.

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Reference

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